Cameras, Devicetree and ACPI: A Device Driver Perspective

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Cameras

- USB webcams
  - Found in many laptops as well as pluggable USB devices
- Complex cameras
  - Typically consisting of
    - Camera module
    - CSI-2 (or parallel) bus receiver
    - Image signal processor (ISP)
  - Virtually all mobile phones
  - Increasingly found in laptops, too

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USB cameras

- Uvcvideo driver implements V4L2 interface applications can use directly
- That’s all you need!

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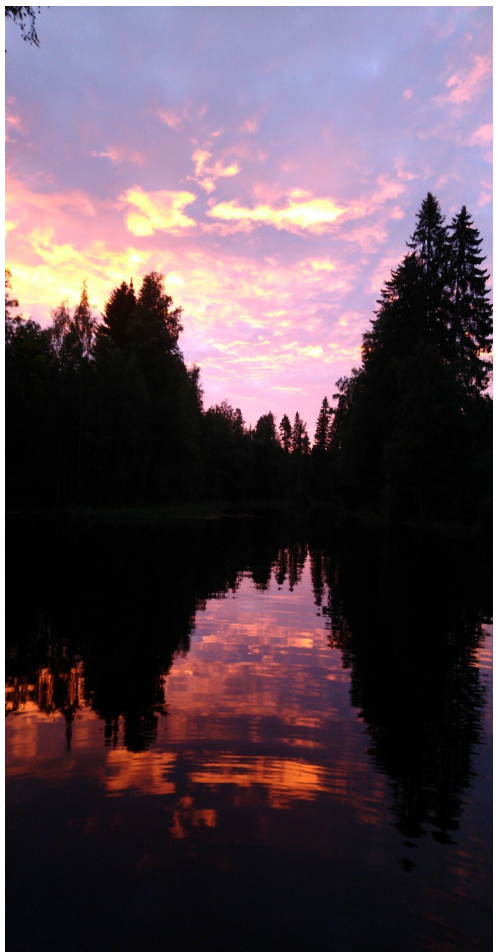
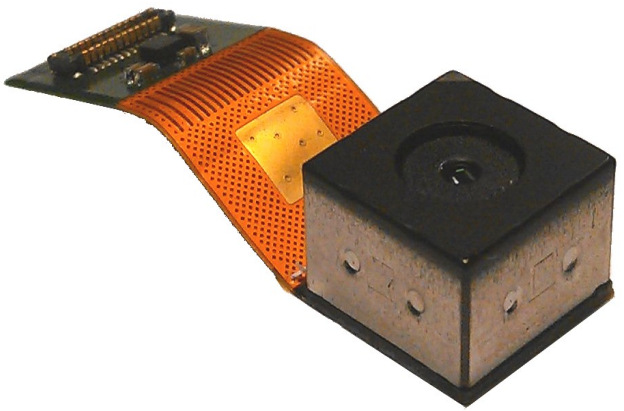
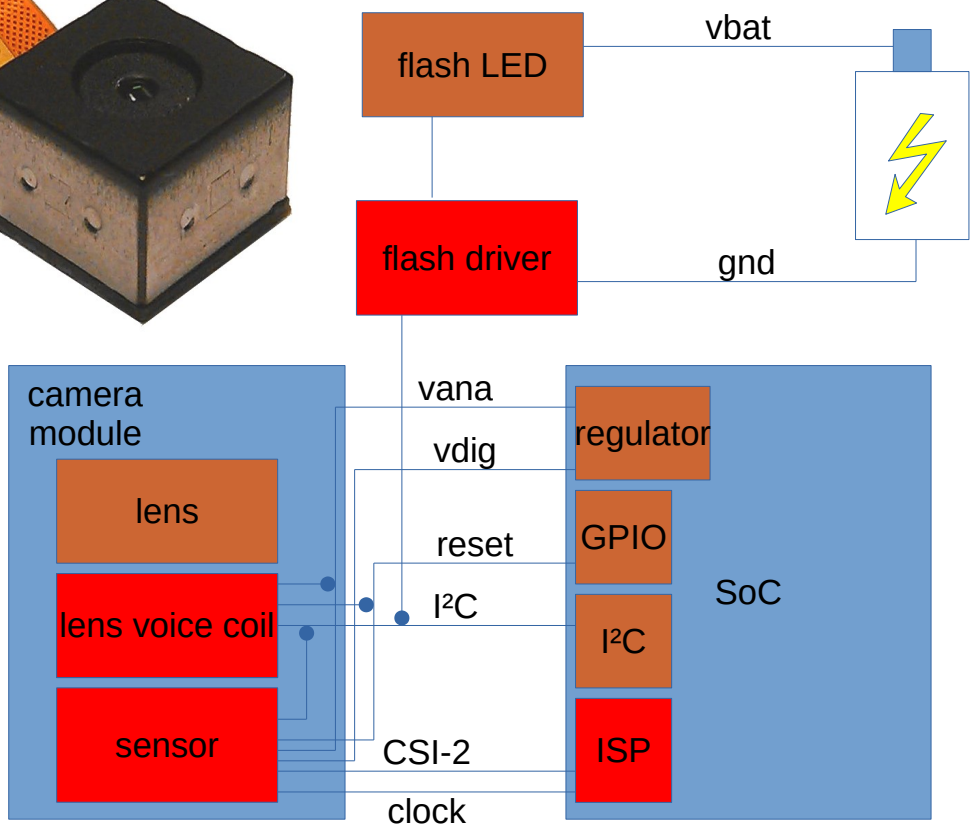
Complex cameras







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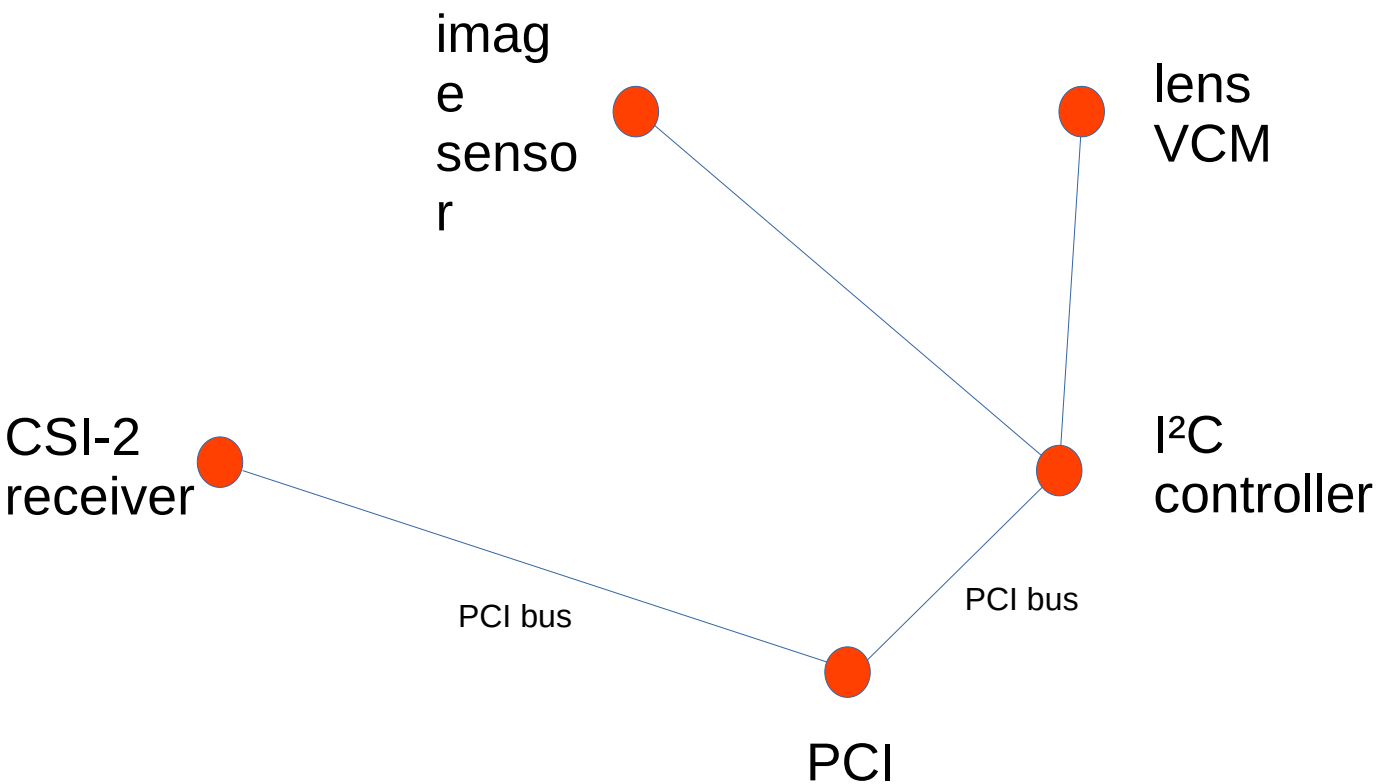
Processing images in complex cameras

- Raw data received in system memory
- Image data processed in ISP (Image Signal Processor)
- Camera control, including control algorithms in user space
- **libcamera**

Bus view



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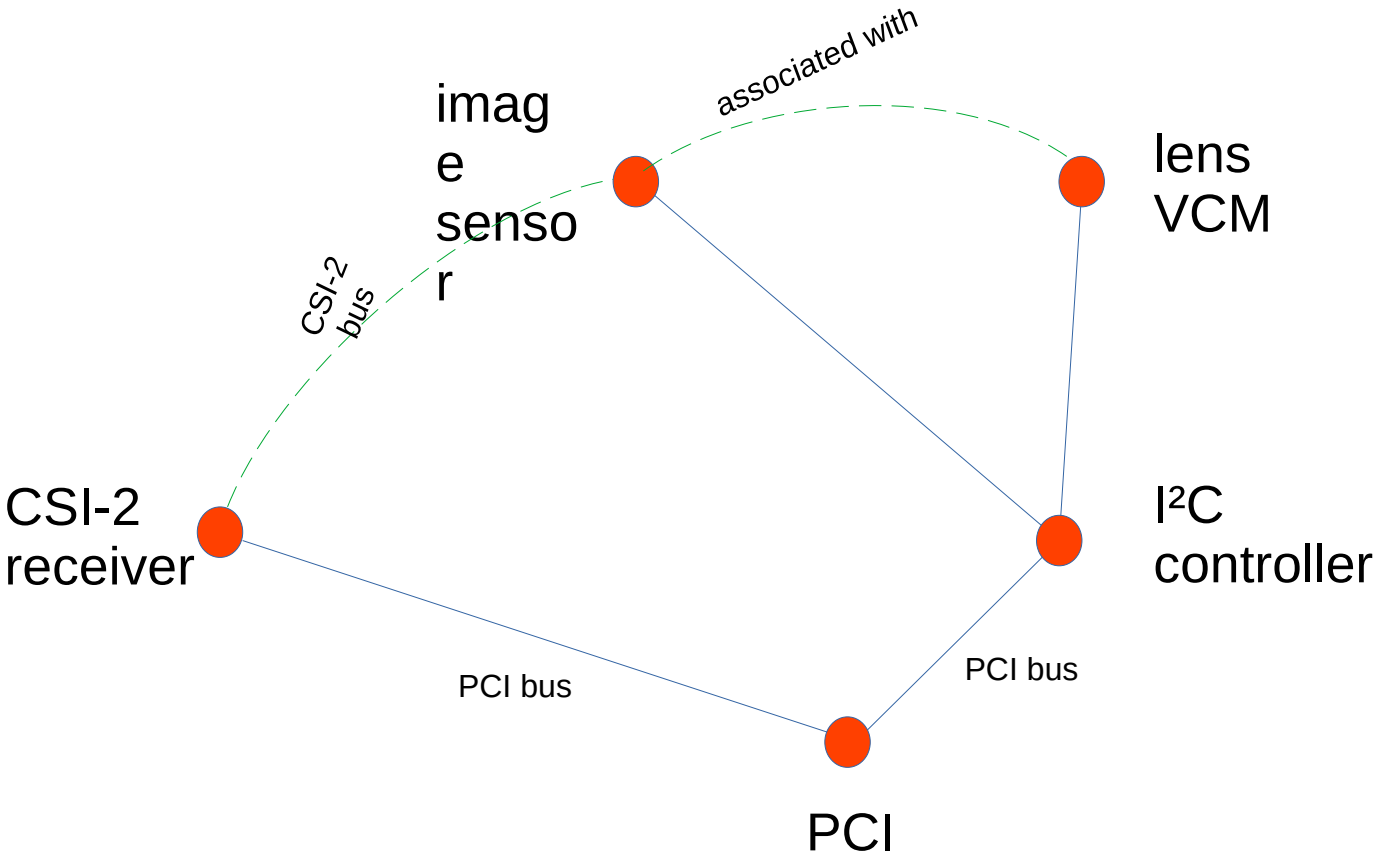
Bus view, with camera related information



- CSI-2 bus also requires connected lanes, PHY type etc.
- Parallel buses have configuration as well

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Camera support in Devicetree and ACPI firmware

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Device tree

- System hardware description
- Originates from Sparc / Open Firmware
- Used on a variety on architectures
  - ARM{,64}, MIPS, PowerPC, Sparc and some x86 systems
- Tree structure
  - Nodes
  - Properties
- Source code compiled into binary (DTB) before use

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Devicetree camera support

- First firmware type to support complex cameras
  - Since 2012
- Bindings defined in dt-schema and kernel
  - `https://github.com/devicetree-org/dt-schema/blob/main/dtschema/schemas/graph.yaml`
  - `Documentation/devicetree/bindings/media/video-interface-devices.yaml`
  - `Documentation/devicetree/bindings/media/video-interfaces.yaml`
  - `Documentation/devicetree/bindings/leds/common.yaml`
  - `Additionally device specific bindings`

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ACPI

- Advanced Configuration and Power Interface
- Operating system independent
- Virtually every PC nowadays
  - Also found in other architectures such as ARM64
- Device discovery and enumeration
- **Power management**
- AML code run in ACPI virtual machine

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ACPI _DSD

- ACPI supports Devicetree-like nodes and properties via _DSD objects
- String references to other nodes
- `https://github.com/UEFI/DSD-Guide/blob/main/src/dsd-guide.adoc`

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ACPI camera support – Linux specific

- Graph and LED definitions amended by
  - `Documentation/firmware-guide/acpi/dsd/graph.rst`
  - `Documentation/firmware-guide/acpi/dsd/leds.rst`
- Otherwise uses DT definitions
- Used in many x86 Chromebooks
- _DSD only
- Support added in 2017

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ACPI camera support – IPU3 specific

- IPU3 specific binary data structures in a few custom ACPI objects
- Found in Skylake and Kaby lake laptops shipped with Windows
- Enables cameras in many laptops
- Some information not available from firmware
- Power management in drivers
- Support added in 2019

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ACPI _CRS

- Used to describe various things such as serial buses
- CSI-2 connection resource descriptor
- Partially describes a CSI-2 bus
- Added in ACPI 6.4

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ACPI camera support – MIPI DisCo for Imaging

- DisCo – Series of MIPI specifications defining ACPI firmware interfaces for MIPI hardware standards
- ACPI _CRS and _DSD
- Vendor and operating system independent
- Expected to be released later this year

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Parsing camera related information from firmware

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Driver developer’s problem

```
if (is_of_node(dev_fwnode(dev)))
      ret = parse_of();
else if (is_acpi_node(dev_fwnode(dev)))
      ret = parse_acpi();
else
      ret = -ENODEV;


???
```

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Parsing camera definitions on ACPI

- Non-Linux specific definitions for ACPI rely at least partially on binary data structures
  - Little or no similarity with Devicetree
- Parser determined based on ACPI objects as well as _DSD data nodes and properties

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V4L2 fwnode framework

- Helps drivers in parsing information from firmware
- Origins in V4L2 OF framework
- Uses fwnode property API to parse Devicetree nodes and properties

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v4l2_fwnode_endpoint_alloc_parse()

- Main function to access Devicetree graph endpoint specific information for sub-devices
- Parses Devicetree compliant data structure of nodes and properties
- v4l2_fwnode_endpoint_free()

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ACPI camera definition parsing – Linux specific

- Fwnode property API ACPI backend
- Graph parsing code for ACPI _DSD nodes and properties
- A few additional checks in graph parsing code in `drivers/acpi/properties.c` for camera definitions

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Software nodes

- Software provide kernel-initialised nodes and properties
- Typically created by other drivers
- Fwnode property API software node backend
- Maybe added to existing fwnodes

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ACPI camera definition parsing – IPU3 specific

- No similarity with Devicetree definitions
- Parsing code located in
  - `drivers/media/pci/intel/ipu3/cio2-bridge.c`
  - `drivers/platform/x86/intel/int3472/`
- New nodes instantiated and properties added based on parsed binary data structure
- Regulators and clocks created

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ACPI camera definition parsing – MIPI DisCo for Imaging

- Combination of ACPI _CRS binary data structure and _DSD nodes and properties
- Software nodes and properties to be created from information in binary data structures
- Yet again the result will be Devicetree-like view to V4L2 fwnode framework!

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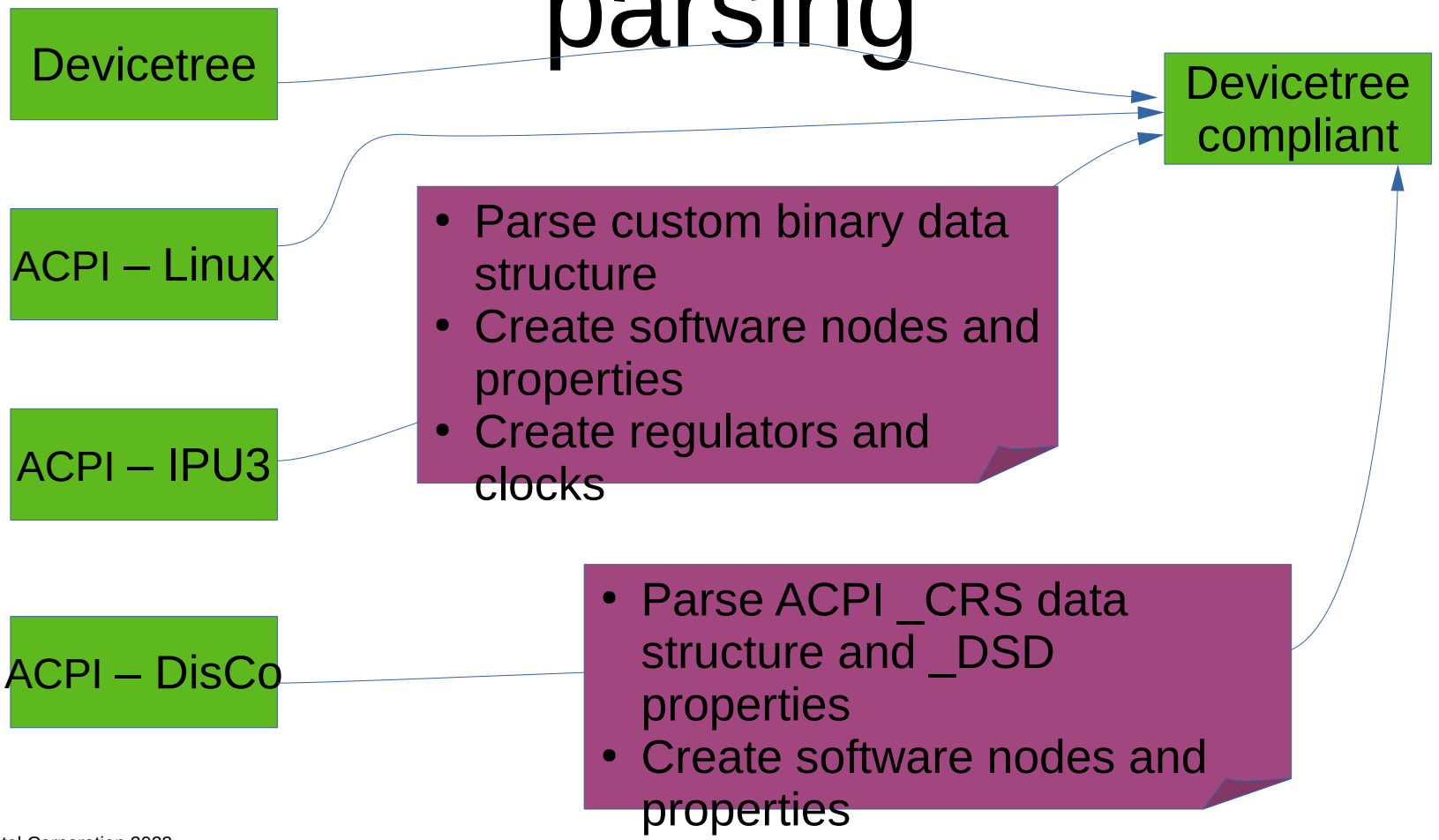
Summary of differences in complex camera firmware parsing



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Driver probe example

```
int driver_probe(struct i2c_client *client)
{
        struct fwnode_handle *fwnode = dev_fwnode(dev);
        struct fwnode_handle *endpoint;
        struct v4l2_fwnode_endpoint vep = { .bus_type = V4L2_MBUS_MIPI_DPHY };
        int ret;

        endpoint =
                fwnode_graph_get_endpoint_by_id(fwnode, 0 /* port */, 0 /* endpoint */,
                                                FWNODE_GRAPH_ENDPOINT_NEXT);

        ret = v4l2_fwnode_endpoint_alloc_parse(endpoint, &vep);
        fwnode_handle_put(endpoint);
        if (ret)
                return ret;

        /* configuration stored in vep */

        v4l2_fwnode_endpoint_free(&vep);

        return ret;
}
```

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struct v4l2_fwnode_endpoint

```
struct v4l2_fwnode_endpoint {
        struct fwnode_endpoint base;
        enum v4l2_mbus_type bus_type;
        struct {
                struct v4l2_mbus_config_parallel parallel;
                struct v4l2_mbus_config_mipi_csi1 mipi_csi1;
                struct v4l2_mbus_config_mipi_csi2 mipi_csi2;
        } bus;
        u64 *link_frequencies;
        unsigned int nr_of_link_frequencies;
};
```

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struct v4l2_mbus_config_mipi_csi2

```
struct v4l2_mbus_config_mipi_csi2 {
        unsigned int flags;
        unsigned char data_lanes[V4L2_MBUS_CSI2_MAX_DATA_LANES];
        unsigned char clock_lane;
        unsigned char num_data_lanes;
        bool lane_polarities[1 + V4L2_MBUS_CSI2_MAX_DATA_LANES];
};
```

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Future work

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Camera module

- Camera module typically consists of
  - Camera sensor
  - Lens and lens VCM
  - IR filter
- Camera control algorithms need detailed information of the properties of the camera module
- Camera module not visible in firmware currently

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Camera module, continued

- Tuning parameters
  - Lens shading table (unless in sensor EEPROM)
  - Other sensor parameters
  - VCM current limits
- Camera module name in DT/ACPI?
- Information on the camera module itself outside kernel

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Power management in ACPI and Devicetree based systems

- ACPI handles power management via _PSx methods and power resources (_PRx)
- In Devicetree systems the driver is responsible for its power on and off sequences
  - Regulators, GPIOs and clocks available to the driver
- Runtime PM supported if CONFIG_PM option enabled

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I²C device power state in driver probe and remove

- I²C devices are powered on for driver probe ACPI based systems
- Off in Devicetree based systems
  - No other option as the driver acquires resources for powering on and off the device during its probe function
- This causes significant complications in writing drivers
- In principle the problem touches all I²C drivers that support both Devicetree and ACPI
  - A large number of such drivers are camera sensor drivers

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I²C device power state in driver probe and remove (continued)

- Further complicated by supporting low power state probe
  - Privacy LED wired to camera sensor power supply
  - ACPI only for now
  - Devicetree support?
- All combinations of
  - CONFIG_PM enabled or disabled
  - Runtime PM may be disabled through sysfs when CONFIG_PM is enabled
  - DT vs. ACPI vs. ACPI but in low power state
- On some ACPI systems you may need regulators, clocks or GPIOs

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Example of power managment in driver probe function

```
int driver_probe(struct i2c_client *client)
{
        int ret, full_power = acpi_dev_state_d0(&client->dev));

        if (full_power) {
                ret = power_on_device(&client->dev);
                if (ret)
                        return -ENODEV;
                ret = identify_device(&client->dev);
                if (ret)
                        goto err_power_off;
                pm_runtime_set_active(&client->dev);
        }

        pm_runtime_enable(&client->dev);
        pm_runtime_idle(&client->dev);
        return 0;

err_power_off:
        if (!pm_runtime_status_suspended(&client->dev))
                power_off_device(&client->dev);
        return ret;
}
```

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Thank you!

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